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100 GHz RADIO SIGNAL OVER 160 GBPS-160 KM ROF LINK USING POLARIZATION DIVISION MULTIPLEXING BASED 256-QAM AND MATCHED FILTER

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ABSTRACT

High capacity communication systems are essential to meet the demand of fifth generation (5G) networks due to the sudden increase in bandwidth-hungry applications over the past few years. Radio over fiber (RoF) incorporating polarization division multiplexing (PDM) is a spectrally efficient and predominant option for high speed and prolonged reach RF enabled optical communication systems. Higher level quadrature amplitude modulations (QAMs) have narrow spectrums and perfect candidate for RoF. However, integration of PDM supported higher QAMs are not explored extensively in RoF technology. Therefore, in this research article, a 160 Gbps-100 GHz RoF system is presented over 160 km link distance by employing PDM-256-QAM and matched filter. Moreover, the eradication of dispersion, time skews, phase compensation and nonlinear effects have been performed by employing different algorithms such as blind phase search (BPS), constant modulus Algorithm (CMA), and viterbi phase estimation (VPE).The presented system is investigated for discerning the effects of different RF frequencies, input powers, matched filter bandwidths on polarization X and y in terms of log bit error rate (log BER), symbol error rate (SER), Q factor, and error vector magnitude (EVM). Results revealed that polarization exhibited better performance as compared to polarization X.

Keywords: PDM, 256-QAM, RoF, log BER, EVM

INTRODUCTION

High-capacity spectrally efficient optical access networks (OAN), and metropolitan networks with expanded reach are now possible thanks to coherent optical technology for offering promising solutions. The widespread use of bandwidth-hungry applications like video-on-demand, online gaming, and other multimedia applications poses huge challenges to existing OANs.

A. Future 6G networks will be extended by 5G communication systems, and polarization multiplexing will be crucial to 6G services. Polarization multiplexing can increase the capacity of optical transmission networks by spreading information across two orthogonal polarization state.

B. The two polarization modes of the laser provide an exceptional way out for the two-fold capacity mechanism in optical fiber communication. The PDM strategy, which combines two linear and orthogonal states of polarization (SOPs) over a single wavelength, is one of the most popular polarization-altering methods.

C. PDM's compatibility with other existing multiplexing techniques such as wavelength, time, code, and mode division multiplexing is a significant advantage.

High-speed hunger and a massive increase in users have soared globally over the past 20 years. Today's communication systems must all have characteristics like internet connectivity, high mobility, and wide coverage.

D.Next-generation networks will be defined by the need for efficient systems that can accommodate large data rates. While optical fiber offers wide bandwidth and enables prolonged reach communication, RF frequencies mitigate bandwidth shortening and spectrum congestion in the wireless realm. RoF is used to control wireless network traffic and offers access to the channel bandwidth. The most viable option to provide direct broadband wireless connectivity to the end user is RoF devices that integrate millimeter waves (MMW). Non-return to zero (NRZ) modulation format was investigated at 10 Gbps carrying 60 GHz millimeter wave (MMW) over a 60km RoF link in [S. Chaudhary, D. Thakur, A. Sharma 2017]. Direct detection and intensity modulation using NRZ and return to zero (RZ) are the rudimentary modulation formats that are employed widely in RoF systems due to their simple architecture and economical traits. However, bandwidth inefficiency in RZ and less power tolerance in NRZ make them unsuitable for high-speed RoF systems. Later on, for getting improved spectral efficiency, pulse amplitude modulation (PAM) modulation format was incorporated in RoF systems such as 10 Gbps-40 GHz MMW enabled 4-PAM-RoF system was reported.

E. The outcomes revealed that the PAM modulation format suffers from less power receiver sensitivity.

F. A comparison between the NRZ and 4-PAM was performed at 10 Gbps and it was seen that NRZ covered 80 km due to better receiver sensitivity while PAM was restricted to 40 km. Similarly, a new range of bi-phase direct detection advanced modulation formats was introduced with high tolerance towards nonlinear and dispersion effects such as compressed, duobinary, and modified RZ. However, their data rate supporting speed was restricted to a maximum of 80 Gbps

G. Differential phase and quadrature phase shift keying (DPSK/DQPSK) are bi-phase and quad-phase modulations based on balanced detection. Sideband suppression of the DPSK spectrum for the long-reach transmission (2520 km) of 60 GHz MMW signals employing wavelength division multiplexing (WDM) was demonstrated in .

H. DPSK modulation has 0 and π phase shifts for adjacent ones in the bit sequence but the error in one bit causes a successive error in the second bit. In DQPSK, noise interference is the major constraint as reported in

I. where a 20 Gbps-60 GHz RoF link was proposed over 50 km.

With the emergence of multilevel modulations, data rates, and data link lengths are significantly improved due to their high spectral efficiency. One of the prominent candidates of multilevel modulations is orthogonal frequency division multiplexing (OFDM) which has the competence to offer high resistance to Intersymbol Interference (ISI) and narrow spectrum. An RoF-OFDM system using different QAMs was reported served a 60 GHz RF signal. An experimental study of a PDM-OFDM system carrying 60 GHz at 52 Gbps was conducted in.

J. They have covered 10 km over single-mode fiber and 3 m over wireless channel employing a 3×3 multi-input-multi-output (MIMO) system. However, the drawback of the high peak-to-average-power ratio (PAPR) in OFDM is a major limitation. Moving further, a noise-resistant multilevel modulation is quadrature amplitude modulation (QAM) which has different variants starting from 4-QAM to n-QAM. The more bits per symbol in the QAM, the higher will the spectral efficiency

K. Quadrature PSK (QPSK) is also a predominant modulation but has lower power efficiency as compared to QAM. The performance of frequency responses of both polarization modulator-based system and Mach Zehender Modulator (MZM) based RoF systems were simulated and evaluated using a 16 QAM. The frequency sensitivity of the polarization modulator can be adjusted. When compared to MZM, which got a BER of 10-14, the polarization modulator achieved a least BER of almost 10-37, implying virtually no transmission error for polarization modulator-based RoF systems

L. An asymmetrical 20 Gbps and 10 Gbps data streams downstream and upstream respectively were supported by a 64-QAM/16-QAM system over 25 km employing single distributed feedback (DFB) laser

M. Laser source has four fundamental traits such as phase, frequency, and time and the utmost important dimension is polarization. All other dimensions were extensively studied in the optical communication systems except polarization. Therefore, the hybridization of polarization and existing modulations is an important task. Moreover, a combination of multilevel modulations and polarization can offer even more enhanced performance due to lower speed electronics in dual polarization as compared to single one. In 2018, a hybrid PDM-DPSK supporting 36 GHz over 150 km was proposed using DSP

N. With the inculcation of DSP, improved results were obtained due to the eradication of dispersion, time skews, equalization, nonlinear effects, and phase errors. Despite the extensive study of RoF systems, desired RF signal bandwidth is not significantly supported by existing systems. High spectral efficiency can be obtained by using more bits per symbol in the QAMs and several interferences, noises, spurious signals, and impairments can be reduced by employing matched filters along with DSP.

Therefore, in this research article, a 160 Gbps-100 GHz RoF system is presented over a 160 km link distance by employing PDM-256-QAM and matched filter. Moreover, the eradication of dispersion, time skews, phase compensation, and nonlinear effects have been performed by employing a DSP module at the coherent receiver. The presented system is investigated for different RF frequencies, input powers, and matched filter bandwidths on polarization X and y in terms of log BER, SER, Q factor, and EVM.

The remaining paper is organized as Section II describes the principles of PDM-256-QAM and the DSP module. Section III lists the system setup of the presented work and Section IV shows the results and discussions of the investigation. The conclusion and future scopes are elaborated in Section V.

PRINCIPLE OF PDM-256-QAM AND DSP

In QAM multilevel modulation, two dimensions are varied such as amplitude as well as phase of the carrier and there is a range of QAM variants such as 4-QAM to n-QAM, where n varies from 1 to 22n. Spectral efficiency in QAMs depends on the bits per symbol such that more are the bits/symbol, the higher will the efficiency of the spectrum. In 256-QAM, the signaling rate reduces to 1/8th of the total rate of the transmission and therefore decreases the pressure on the electronics speed and offers better performance. Moreover, symbols in the constellation are uniformly located in the I-Q plane and symbol errors are minimized. The 256-QAM has a high potential to offer high bandwidth efficiency, increased tolerance towards noises, and show fewer bit errors. An integration of 256-QAM and PDM open up a new window for high-capacity and long reach optical communication systems. The PDM has two or more different polarization states that have the potential to multiply the data rate of the system. In coherent optical systems, time skews, phase errors, and nonlinear effects are predominant performance degrading limitations and these can be eradicated by placing DSP in the coherent receiver of QAM. A universal DSP performs the following functions such as add noise, DC blocking, normalization, and signal recovery followed by algorithms. Algorithm stages are Bessel filter, resampling, Quadrature Imbalance (QI) Compensation, dispersion compensation, time recovery, nonlinear compensation, adaptive Equalizer, phase estimation, and correction. Three different algorithms named CMA, BPS, and VPE are operational in DSP. Coherent detection systems can use matched filters, which improve the signal-to-noise ratio (SNR) of the signal being detected concerning the noise. Because it only allows approved signals to pass, this filter offers excellent anti-jamming qualities

SYSTEM SETUP

Figure 1 represents the block diagram of the proposed PDM-256-QAM 100 GHz RoF system employing DSP and matched filter. The potential of capacity doubling in PDM makes it a perfect candidate for current-generation optical communication systems. A symbol rate of 10 Gbps is considered and the total speed of the system is 160 Gbps (symbol rate × bits /symbol (8) × polarization states (2)).

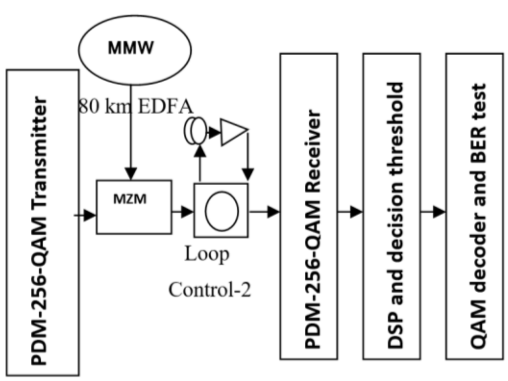


Fig.1: Block diagram of proposed PDM-256-QAM based RoF system

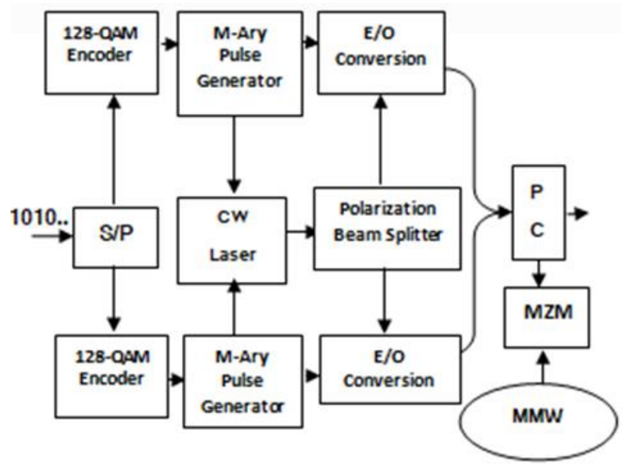


Fig.2: Representation of PDM-256-QAM transmitter with MMW signal

E/O-Electrical to optical; PC-Polarization Combiner; S/P- Serial to parallel

In the PDM-256-QAM transmitter, the serial data stream of binary bits is converted into parallel data by incorporating serial to parallel converter, and these parallel outputs are fed to the QAM encoders having 8 bits per symbol. Further, real and imaginary symbols are assigned multilevel raised cosine pulses according to the M-ary signal input. To convert these multilevel raised cosine pulses into an optical domain through PDM, a single laser output at 193.1 THz is divided into two polarizations such as polarization X (00), and polarization Y (900), and assigned to MZM modulators. Polarization X and polarization Y encoded signals are further multiplexed using a polarization combiner. For the RF signal modulation over PDM-256-QAM data, a sine generator frequency and peak-biased MZM are employed after the PDM-256-QAM transmitter. Fig.2. depict the block diagram of the proposed transmitter with an MMW signal. The transmission of the radio signal is performed through 160 km (80 km + 80 km) single mode fiber and optical erbium doped amplifier (EDFA) having 40 dB total gain (20 dB for 80 km) and 8 dB noise figure (4 dB for 80km).

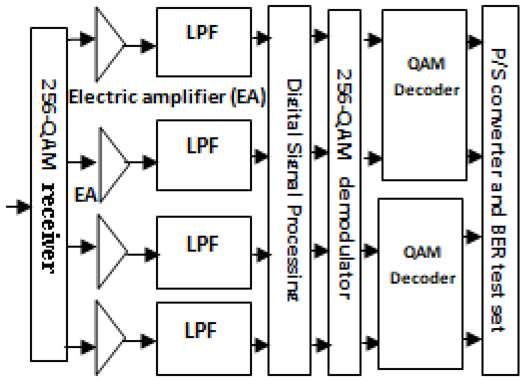


Fig.3: PDM-256-QAM receiver and DSP

After the successful transmission of the signal, matched filter having particular bandwidth is employed to remove the undesired noises. The output of the matched filter is given to the PDM-256-QAM coherent receiver consisting of the local oscillator for phase matching of symbols, polarization splitter for the polarization X and y signals, and balanced photodetectors. After the balanced photodetection, the DSP module is placed to eradicate the time skews, phase errors, and nonlinear effects as shown in Fig.3. Constellation analyzers are placed for polarization X and y to check the I/Q placement of symbols and EVM of symbols. Further, parallel QAM bits are decoded using QAM decoders for both polarizations, and data is evaluated at the BER test set. TABLE I shows the simulation parameters considered to complete the proposed work.

Table 1. Simulation parameters of proposed PDM-256-QAM based RoF system

Parameter	Values
Data rate	160 Gbps
Symbol rate	10 Gbps
QAM bits per symbol	8
QAM variant	PDM-256-QAM
Sequence length	65536
Number of samples	2097152
CW laser power	0 dB – 20 dB
Linewidth	100e-012 MHz
RF frequency	40 GHz to 120 GHz
SMF length	160 km
EDFA Gain and noise figure	20 dB and 4 dB
Matched filter bandwidth	10 GHz to 50 GHz
Photo-detectors	PIN
DSP algorithms	CMA, BPS and VPE

RESULTS AND DISCUSSIONS

Optiwave Optisystem simulation software is considered for the completion of proposed RF enabled PDM-256-QAM system.

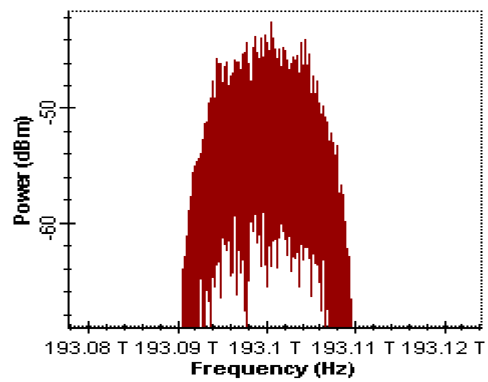


Fig. 4 (a): Optical carrier spectrum after PDM-256-QAM transmitter

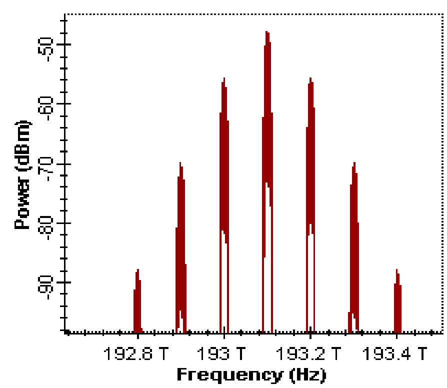


Fig. 4 (b): Optical carrier spectrum after RF modulation

Fig. 4 (a) represents the optical carrier spectrum of PDM-256-QAM transmitter having input power 10 dB and center frequency 193.1 THz. However, the insertion loss of different components cause power loss and only -42 dB power reached at the optical carrier spectrum analyzer. Fig. 4(b). illustrates the optical carrier spectrum after the modulation of RF signal. It is observed that the multiple frequency combs are emerged in the optical carrier spectrum.

Further, effects of input RF frequency on the output log BER of the proposed has been seen for polarization X and polarization Y as shown in Fig. 4. Input RF frequencies are varied from 40 GHz to 120 GHz for checking the highest supported RF signal supported by proposed system. Results revealed that log BER of polarization X tends to increase with the increase in RF frequency but in case of polarization Y, trend is just opposite such that higher RF frequencies have lower log BER. In order to select the maximum RF frequency where both the polarizations provide acceptable log BER is found out to be 100 GHz. Log BER values at 100 GHz are -2.89 and -2.98 for polarization X and polarization Y respectively.

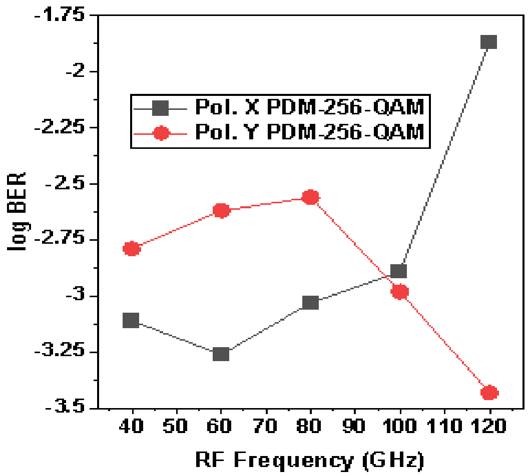


Fig. 5: Effects of RF input on the output log BER of proposed RoF system

Input power in the optical communication systems is an important parameter that can decide the performance of the system. In proposed system, the input power from cw laser is varied from 0 dB to 20 dB at frequency 193.1 THz as shown in Fig. 6. Q factor values of both polarization X and polarization Y increases with the increase in the input power. However, Q factor is higher in case of polarization Y as compared to polarization X. It is noteworthy that Q factor excel till 15 dB input power and later on tends to decrease and therefore 15 dB is an optimal power level in this case. Values of Q factor at 15 dB and 20 dB are 4.55, 4.34 and 4.33, 4.57 for polarization X and polarization Y respectively at 160 km link distance.

Symbol error rate is the measure for the desired placements of the symbols in I-Q plane. A little distortion or crossover of symbols in the quadrant can cause high EVM. Therefore, effects of the bandwidth of matched filter on the SER are explored in Fig. 7 for polarization X and polarization Y.

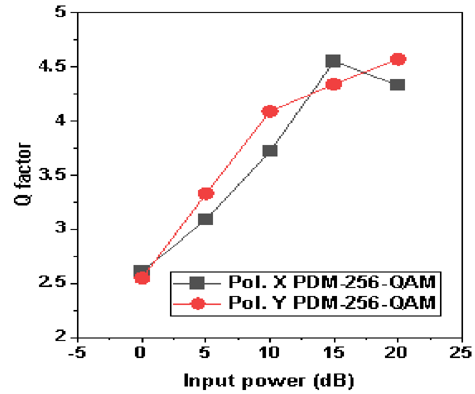


Fig. 6: Variation of Q factor at different input power levels for polarization X and polarization Y

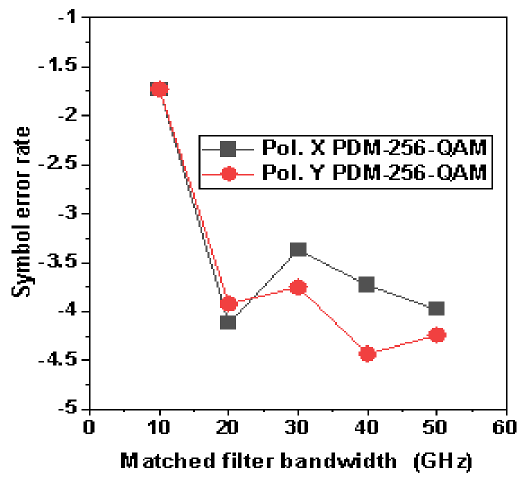
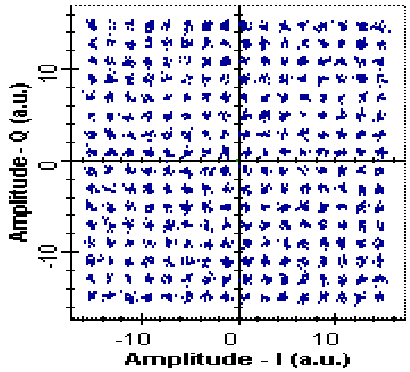


Fig. 7: SER versus matched filter bandwidth

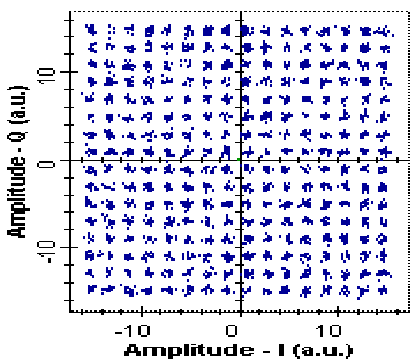
The filter bandwidth started from 10 GHz and varied up to 60 GHz and it is perceived that higher bandwidth can offer better SER. SER is more enhanced in polarization Y as compared to polarization X. Values of SER at 160 km for 10 GHz and 50 GHz are -1.73, -1.73, and -3.98, -4.24 in the case of polarization X and polarization Y respectively.

The Constellation analyzer shows a constellation diagram of the electrical signals in phase and quadrature. Moreover, it can show the polar diagram and calculate the likelihood of a symbol mistake in M-ary signals. Constellation diagrams for PDM-256-QAM at 160 km carrying 100 GHz RF signal are depicted in Fig.

8 (a). for polarization X and Fig. 8 (b) for polarization Y. It is observed that all the symbols are located at their respective positions without interfering with other quadrants for both the polarizations.



(a)



(b)

Fig. 8: Constellation diagram of (a) polarization X and (b) polarization Y at 160 km RoF distance

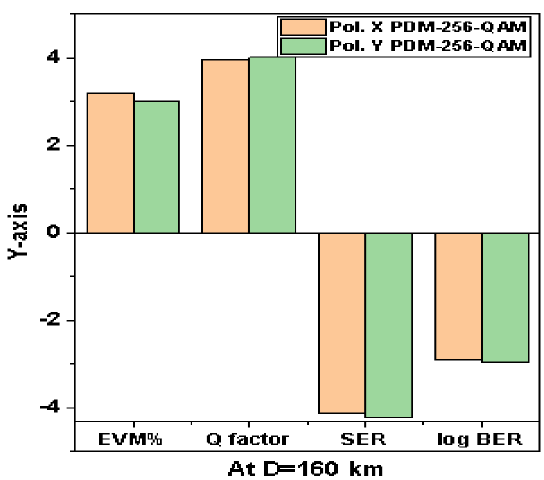


Fig. 9: Bar graph of different output parameters at 160 km for polarization X and polarization Y

TABLE 2 Values of different output parameters at 160 km RoF distance for polarization X and polarization Y

At D=160 km	Pol. X PDM-256-QAM	Pol. Y PDM-256-QAM
EVM%	3.19	3.02
Q factor	3.97	4.02
SER	-4.15	-4.24
log BER	-2.89	-2.98

A bar graph for EVM, SER, Q factor and log BER values are illustrated at 160 km RoF distance for polarization X and polarization Y in Fig. 9. TABLE II shows that polarization Y is better than polarization X in terms of Q factor, EVM, SER and log BER.

CONCLUSION

In this research article, a 160 Gbps-100 GHz RoF system is presented over a 160 km link distance by employing PDM-256-QAM and matched filter. Moreover, the eradication of dispersion, time skews, phase compensation, and nonlinear effects have been performed by employing different algorithms such as BPS, CMA, and VPE. The presented system is investigated at different RF frequencies, input powers, and matched filter bandwidths on polarization X and y in terms of log BER, SER, Q factor, and EVM. Input RF frequencies are varied from 40 GHz to 120 GHz and the maximum RF frequency where both the polarizations provide acceptable log BER is found to be 100 GHz. Log BER values at 100 GHz are -2.89 and -2.98 for polarization X and polarization Y respectively. Further, input power is varied from 0 dB to 20 dB and results revealed that 15 dB input power is most suitable for the proposed system. Also, values obtained for SER at 160 km for 10 GHz, 40 GHz, and 50 GHz are -1.73, -1.73 and -3.73, -4.43, and -3.98,

-4.24 in the case of polarization X and polarization Y respectively. Therefore, the 40 GHz bandwidth of the matched filter is found to be best. Constellation diagrams show that symbols are well placed in the I-Q planes of 256-QAM quadrants. Results revealed that polarization exhibited better performance as compared to polarization X. The presented system is competent to support high RF frequencies; high speed and can cover long distances. In near future, the WDM-PDM system can be investigated using 256-QAM.

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